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(54) **TESTING RESPONSES OF SOFTWARE APPLICATIONS TO SPATIOTEMPORAL EVENTS USING SIMULATED ENVIRONMENTS**

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(58) **Field of Classification Search**  
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(Continued)

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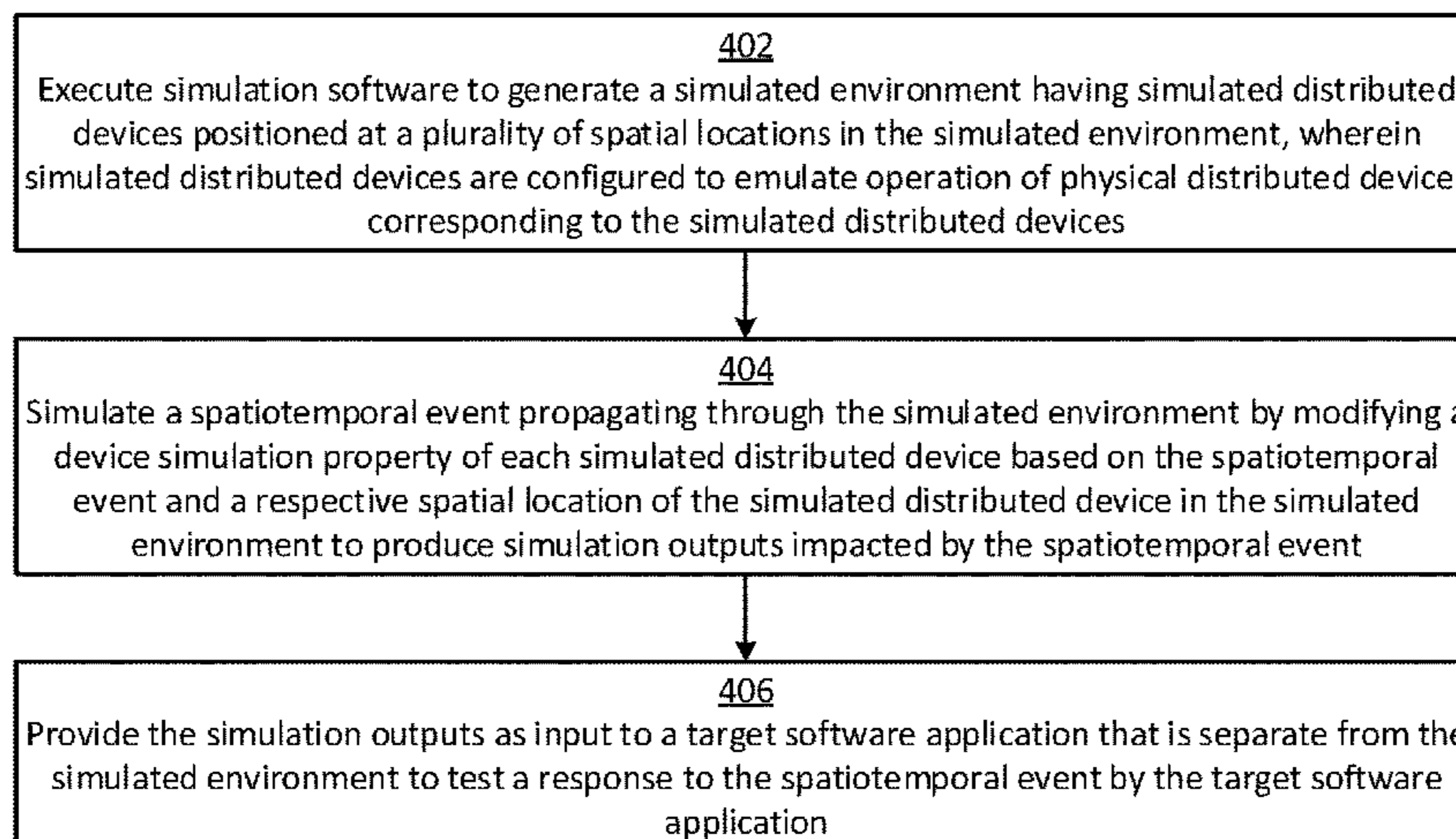
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(57) **ABSTRACT**

Responses of software applications to spatiotemporal events can be tested using simulated environments. In one example, a system can generate a simulated environment having simulated distributed devices positioned at various spatial locations in the simulated environment. The system can then simulate a spatiotemporal event propagating through the simulated environment by modifying a device simulation property of each simulated distributed device based on the spatiotemporal event and a respective spatial location of the simulated distributed device in the simulated environment. This can produce simulation outputs impacted by the spatiotemporal event. The system can then provide the simulation outputs as input to a target software application to test a response to the spatiotemporal event by the target software application.

**20 Claims, 4 Drawing Sheets**



(58) **Field of Classification Search**  
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See application file for complete search history.

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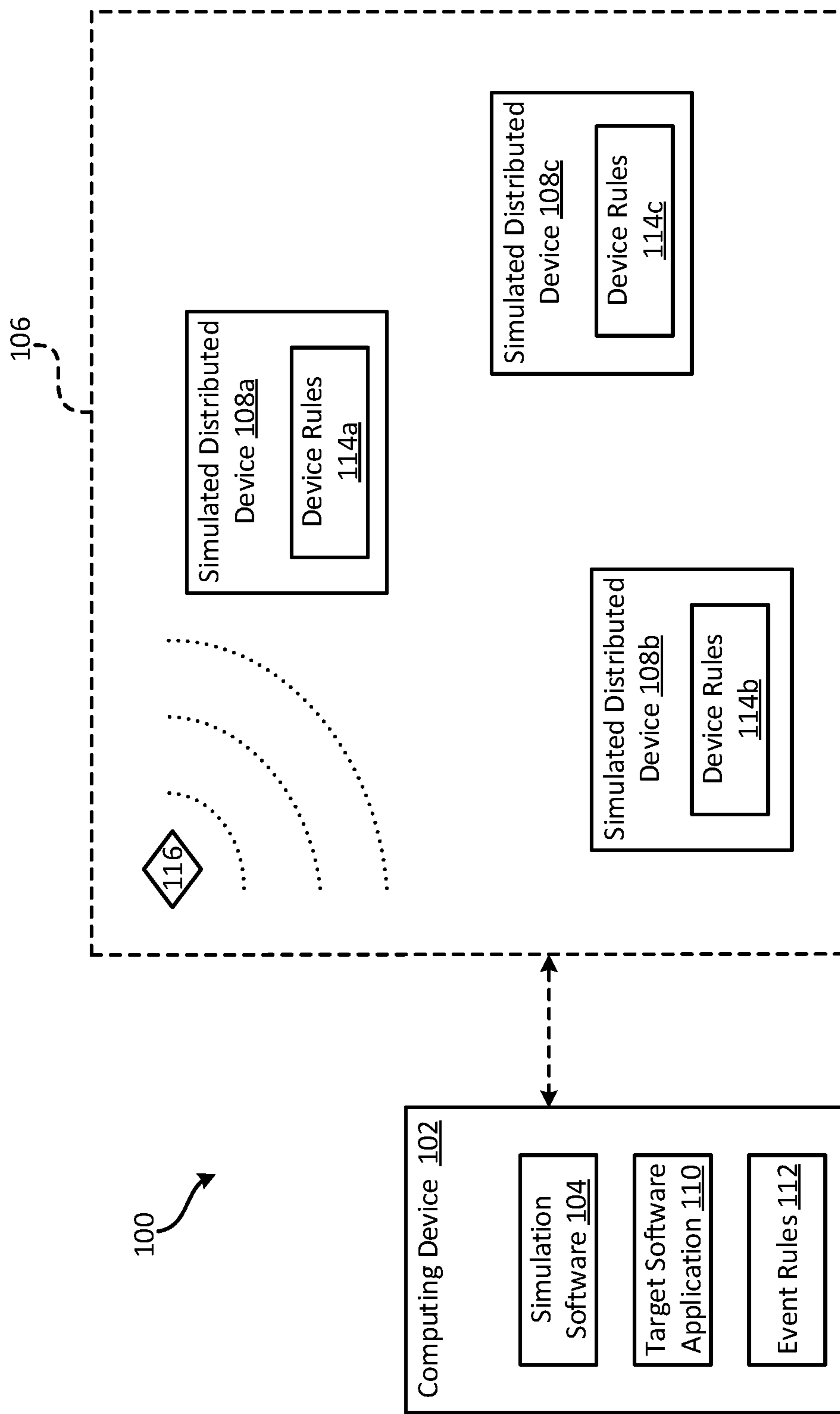


FIG. 1

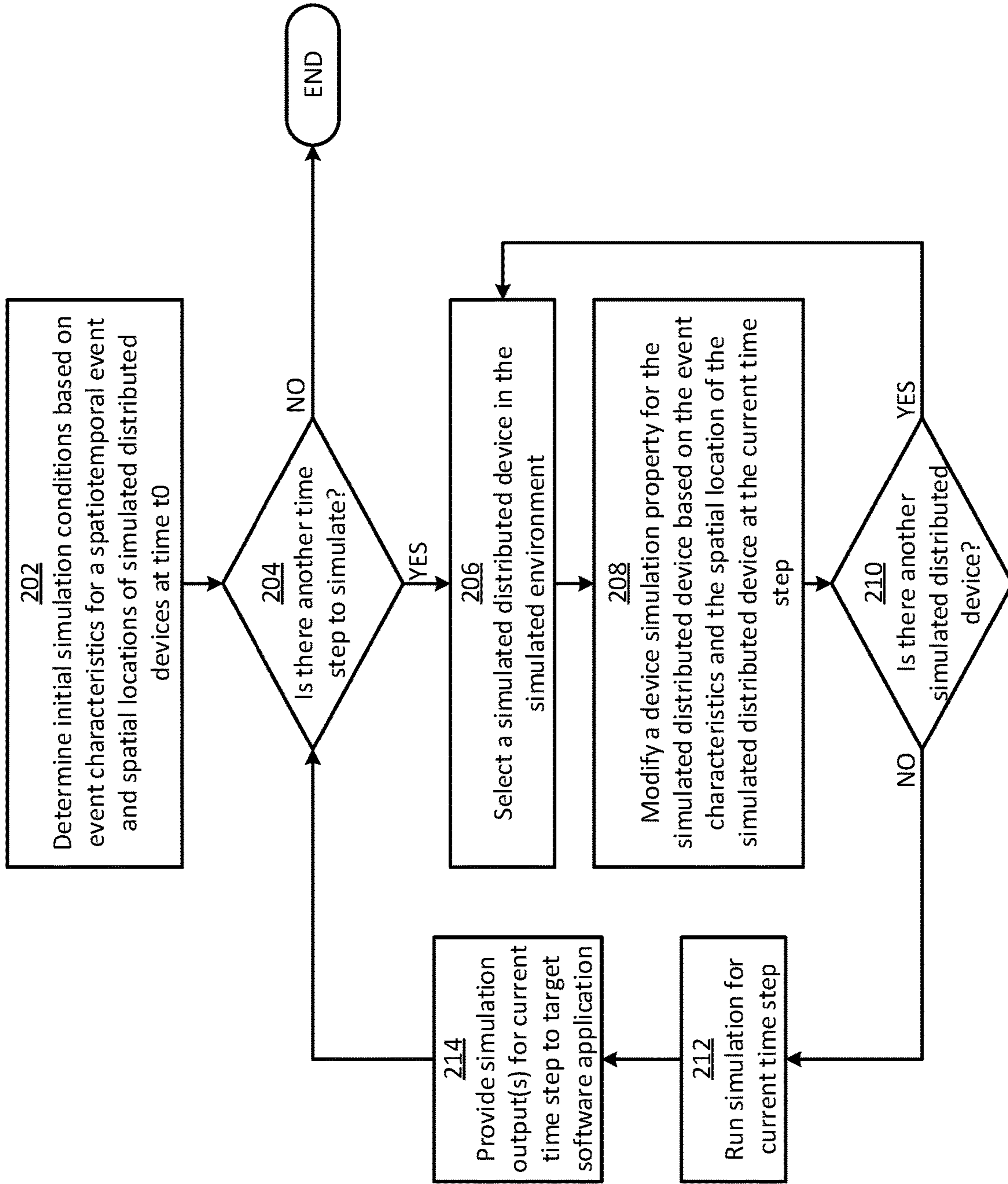


FIG. 2



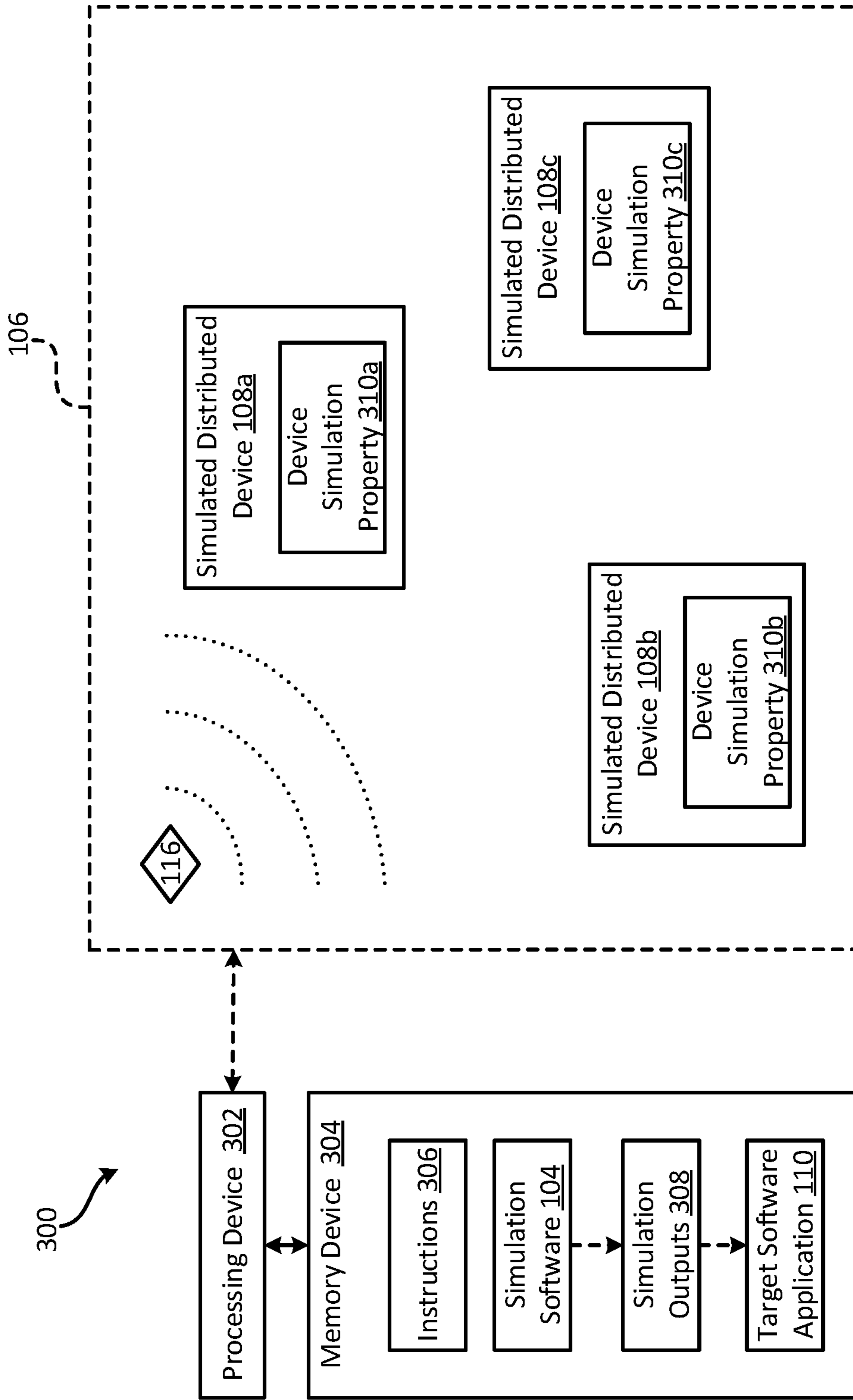


FIG. 3

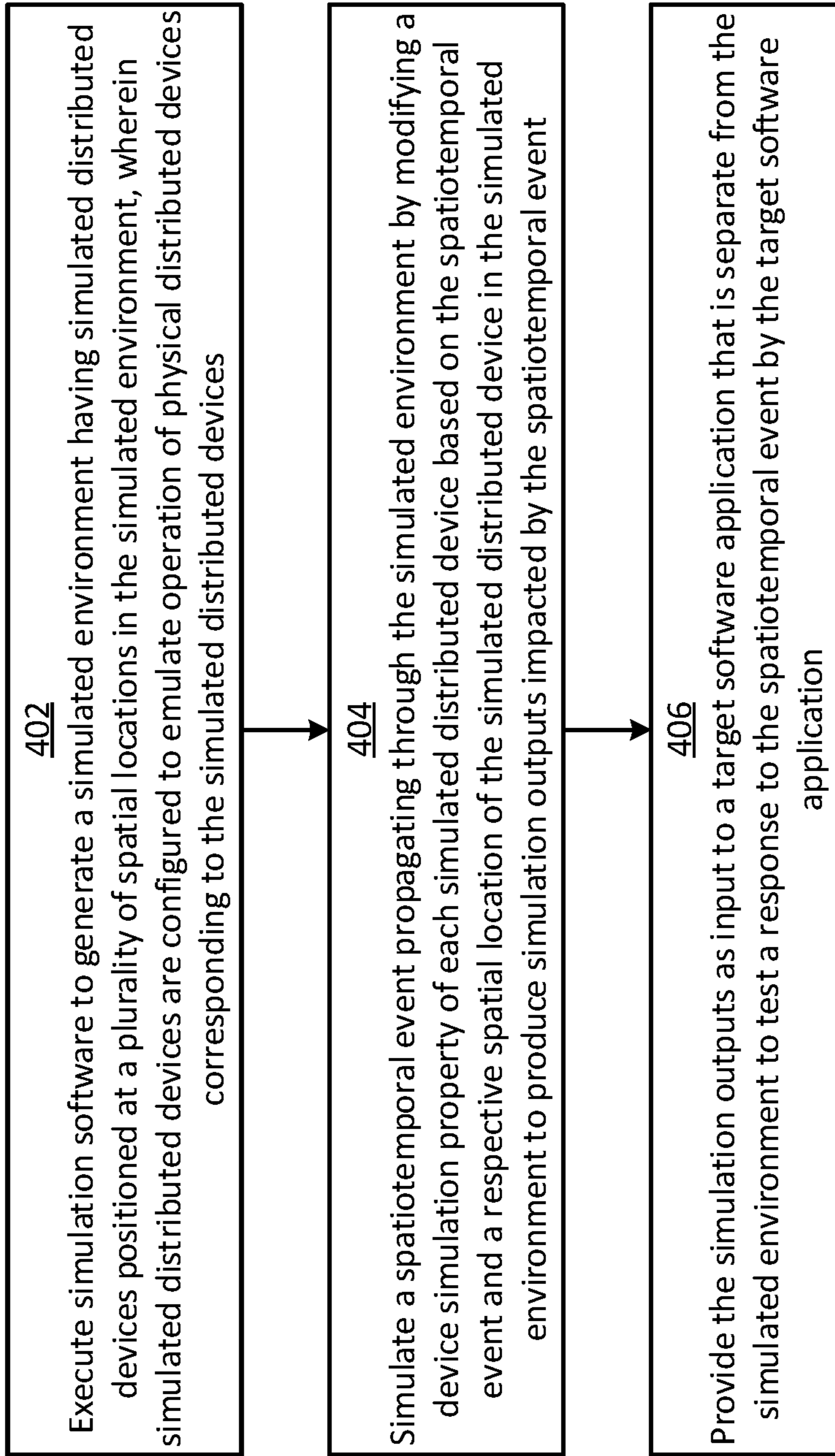


FIG. 4



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## TESTING RESPONSES OF SOFTWARE APPLICATIONS TO SPATIOTEMPORAL EVENTS USING SIMULATED ENVIRONMENTS

### REFERENCE TO RELATED APPLICATION

This is a continuation of co-pending U.S. patent application Ser. No. 16/403,947, titled "Testing Responses of Software Applications to Spatiotemporal Events Using Simulated Environments" and filed on May 6, 2019, the entirety of which is hereby incorporated by reference.

### TECHNICAL FIELD

The present disclosure relates generally to software testing. More specifically, but not by way of limitation, this disclosure relates to testing responses of software applications to spatiotemporal events using simulated environments.

### BACKGROUND

Recently, there has been a proliferation of distributed devices. Distributed devices are electronic devices configured to form part of a distributed system (an ecosystem of electronic devices collectively working together to achieve a common goal). The distributed devices typically detect a variety of environmental conditions using sensors and transmit data associated with such environmental conditions to a software application, which may be executing in a cloud computing environment. The software application can receive the data from the distributed devices and respond to the data in a variety of ways.

### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 depicts a block diagram of an example of a system for testing responses of software applications to spatiotemporal events using simulated environments according to some aspects.

FIG. 2 depicts a flow chart of an example of a process for testing responses of software applications to spatiotemporal events using simulated environments according to some aspects.

FIG. 3 depicts a block diagram of another example of a system for testing responses of software applications to spatiotemporal events using simulated environments according to some aspects.

FIG. 4 depicts a flow chart of another example of a process for testing responses of software applications to spatiotemporal events using simulated environments according to some aspects.

### DETAILED DESCRIPTION

Spatiotemporal events can affect a distributed system of distributed devices in different ways over time. A spatiotemporal event is any event that has both spatial and temporal qualities, for example an event that changes in spatial impact over time, such as a fire or natural disaster. Due to the complex nature of spatiotemporal events, it can be challenging to test how a software application designed for use with the distributed devices will respond to such events. For example, a software developer may be developing a software application configured to receive inputs from distributed devices in a real-world environment and respond to

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such inputs. To fully test the software application, the software developer may wish to test how the software application responds to a spatiotemporal event propagating through the real-world environment. But there are currently no easy or effective ways to do so. For example, a software developer may have to actually create a network of distributed devices and manually manipulate the distributed devices (e.g., by shaking them, holding a flame near them, blowing air or smoke on them, etc.) over time to mimic the spatiotemporal event and thereby test the software application. This is time consuming, rudimentary, and inaccurate.

Some examples of the present disclosure overcome one or more of the abovementioned issues through the use of simulation software that can generate simulated distributed devices and manipulate them to produce simulation outputs emulating how a spatiotemporal event impacts the simulated distributed devices over space and time. The simulation outputs can then be supplied as input to a target software application to test how the target software application would respond to the spatiotemporal event. This can enable developers to more quickly and accurately test their software applications.

More specifically, a system of the present disclosure can execute simulation software to generate a simulated environment with simulated distributed devices. The simulated environment can emulate physical characteristics of a real-world environment. For example, the simulated environment can be a three-dimensional (3D) environment that mimics the physical properties of its real-world analogue through simulated changes in pressure, temperature, visibility, ambient light, sound types or levels, or any combination of these. And the simulated distributed devices can emulate the physical distributed devices corresponding thereto in the real world. For example, the simulated distributed devices can be simulated Internet-of-Things (IOT) devices that mimic how their real-world analogues operate. The simulated distributed devices can be positioned at various spatial locations (e.g., 3D coordinates) in the simulated environment imitating how they would actually be positioned in the real world. The system can then run a simulation using the simulated environment to produce simulation outputs.

In some examples, the simulation can at least partially involve emulating a spatiotemporal event occurring in the real world to test a response of the target software application to such an event. For example, the system can simulate a fire spreading spatially through the simulated environment over a series of time steps. To do so, the system can modify device simulation properties associated with the simulated distributed devices at each time step based on (i) an event characteristic at the time step, and (ii) the respective spatial locations of the simulated distributed devices in the simulated environment at the time step. This can produce simulation outputs that are at least partially impacted by the simulated spatiotemporal event. The system can then provide those simulation outputs to a target software application to test the target software application.

These illustrative examples are given to introduce the reader to the general subject matter discussed here and are not intended to limit the scope of the disclosed concepts. The following sections describe various additional features and examples with reference to the drawings in which like numerals indicate like elements but, like the illustrative examples, should not be used to limit the present disclosure.

FIG. 1 is a block diagram of an example of a system 100 for testing responses of software applications to spatiotemporal events using simulated environments. In this example, the system 100 includes a computing device 102, such as a



server or desktop computer. The computing device **102** includes simulation software **104** for generating a simulated environment **106**. The simulated environment **106** can be configured to mimic the physical properties of a real-world environment. For example, the simulated environment **106** can have one or more simulated environmental properties, such as a simulated temperature, pressure, ambient-light level, time-of-day, or sound level, which may or may not dynamically change over the course of a simulation. In some examples, the simulation software **104** is included in a container image that is deployable using a container-deployment engine (e.g., Docker™) to generate the simulated environment **106** in a cloud computing environment.

The simulation software **104** can also generate one or more types of simulated distributed devices **108a-c** within the simulated environment **106**. The simulated distributed devices **108a-c** are simulated analogues of physical distributed devices in the real world. For example, the simulated distributed devices **108a-c** can be simulated IOT devices configured to emulate the behavior of physical IOT devices in the real world.

The simulated distributed devices **108a-c** have device simulation properties that may or may not dynamically change over the course of a simulation. The device simulation properties are at least partially governed by device rules **114a** (e.g., statistical distributions, mathematical functions, or mathematical models) characterizing the behavior of the physical distributed devices in the real world. As one example, the simulated distributed devices **108a-c** can produce simulated sensor measurements that are governed by a statistical distribution, such as a normal distribution. This, in turn, may be dependent on one or more other factors, such as a simulated environmental property in the simulated environment **106**. As another example, the simulated distributed devices **108a-c** can have simulated operational states that are governed by a mathematical function. This, in turn, may be dependent on one or more other factors, such as a simulated environmental property in the simulated environment **106**.

The computing device **102** can execute a simulation associated with the simulated environment **106** over a series of time steps to obtain simulation outputs. The simulation outputs can indicate, for example, simulated sensor measurements from the simulated distributed devices **108a-c** or simulated operational states of the simulated distributed devices **108a-c**. The computing device **102** may then provide the simulation outputs as input to a target software application **110** (e.g., an IOT application), to elicit a response from the target software application **110**. Examples of the response can include an error or a certain output. A developer of the target software application **110** can assess this response and correct the target software application **110**, if needed.

In some cases, a developer may wish to determine how the target software application **110** would respond to dynamically changing conditions in the real world, particularly where the conditions that are dynamically changing in response to a spatiotemporal event, such as a fire, earthquake, explosion, etc. So, some examples of the present disclosure can simulate the propagation of a spatiotemporal event through the simulated environment **106** over a series of time steps. This can produce simulation outputs that are impacted by the simulated spatiotemporal event. These simulation outputs can then be provided as input to the target software application **110**, to enable a developer to see how the target software application **110** would respond to such a spatiotemporal event.

To simulate the spatiotemporal event **116**, the system **100** can include one or more event rules **112** (e.g., statistical distributions, mathematical functions, or mathematical models) characterizing the behavior of the spatiotemporal event in the real world. For example, the spatiotemporal event **116** to be simulated can be a wildfire. In some such examples, the system **100** can simulate the wildfire in the simulated environment **106** by using event rules **112** comprising the mathematical model(s) found in Richard C. Rothermel, *A Mathematical Model for Predicting Fire Spread in Wildland Fuels*, USDA Forest Service Research Paper, INT-115 (1972). The system **100** can include any number and combination of event rules to simulate any number and combination of spatiotemporal events in the simulated environment **106**.

The system **100** may also receive one or more user customizations as to how to simulate the spatiotemporal event **116** in the simulated environment **106**. For example, a user may be able to specify a starting location, ending location, trajectory, path, speed, starting intensity, ending intensity, or other property of the spatiotemporal event **116** to be simulated in the simulated environment **106**. The system **100** can then simulate the spatiotemporal event **116** in accordance with such user customizations.

In some examples, the system **100** can simulate the spatiotemporal event **116** by modifying the device simulation properties (defined by the device rules **114a-c**) based on event characteristics (defined by the event rules **112**). For example, the system **100** can determine location information associated with the simulated distributed device **108a** in the simulated environment **106**. In some examples, the location information includes an absolute location of the simulated distributed device **108a** in the simulated environment **106**, a relative location of the simulated distributed device **108a** in relation to the spatiotemporal event **116** in the simulated environment **106**, or a distance between the simulated distributed device **108a** and the spatiotemporal event **116** in the simulated environment **106**. The system **100** can then use the location information in combination with the event rules **112** to determine how to modify the device simulation properties for the simulated distributed device **108a**. For example, the system **100** can apply the location information (i) as a variable value for a mathematical equation in the event rules **112**, (ii) as a function parameter for a function in the event rules **112**, (iii) to perform a mapping in a lookup table of the event rules **112**, (iv) to determine a distribution value in accordance with a statistical distribution of the event rules **112**, or (v) any combination of these. This can produce a result indicating how the spatiotemporal event **116** would impact the simulated distributed device **108a** given its location in the simulated environment **106**. The system **100** can then modify the device simulation properties for the simulated distributed device **108a** based on this result. For example, the system **100** can modify the device rules **112a** underlying the device simulation properties based on this result, thereby adjusting the device simulation properties. The system **100** can further apply a similar approach to some or all of the other simulated distributed devices **108b-c**, based on their respective locations in the simulated environment **106**, to modify the device simulation properties thereof.

After modifying the device simulation properties of some or all of the simulated distributed devices **108a-c**, the system **100** can then run the simulation to produce simulation outputs (e.g., a set of simulated sensor measurements or a set of simulated operational states of the simulated distribution devices **108a-c**) impacted by the spatiotemporal event **116**.



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In some examples, the simulation outputs are for a particular time step. So, the system **100** can repeat this process for each time step to be simulated, modifying the device simulation properties for the simulated distributed devices **114a-c** based on the locations of the simulated distributed devices **114a-c** in the simulated environment **106** and the event characteristics at the time step, in order to produce a group of simulation outputs. The group of simulation outputs can indicate the impact of the spatiotemporal event **116** propagating through the simulated environment **106** (e.g., as depicted with dotted lines in FIG. 1) on the simulated distributed devices **108a-c**. This process is described in greater detail below with respect to FIG. 2. The group of simulation outputs can then be provided as input to the target software application **110**, for example, to obtain insights into the target software application **110** may respond to a real-world analogue of the spatiotemporal event **116**.

FIG. 2 depicts a flow chart of an example of a process for testing responses of software applications to spatiotemporal events using simulated environments according to some aspects. Other examples can include more steps, fewer steps, different steps, or a different order of the steps than is shown in FIG. 2. The steps of FIG. 2 are discussed below with reference to the components discussed above in relation to FIG. 1.

In block **202**, a computing device **102** determines initial simulation conditions based on (i) event characteristics for a spatiotemporal event **116** at time  $t_0$ , and (ii) spatial locations of simulated distributed devices **108a-c** in a simulated environment **106** at time  $t_0$ . For example, this step may involve setting initial or default values for the simulated environmental properties associated with the simulated environment **106**. Additionally or alternatively, this step may involve setting initial or default values for device rules **114a-c** associated with the simulated distributed devices **108a-c**. Additionally or alternatively, this step may involve setting initial or default values for event characteristics associated with the spatiotemporal event **116**.

In block **204**, the computing device **102** determines if there are any other time steps to simulate. For example, the user may specify that a series of 100 consecutive time steps are to be simulated, where  $t_0$  is just the first time step in the series. If the computing device **102** determines that there is another time step to simulate (e.g., that the end of the series of time steps has not yet been reached), the process continues to block **206**. Otherwise, the process can end.

In block **206**, the computing device **102** selects a simulated distributed device **108a** in the simulated environment **106**. For example, the computing device **102** can select a simulated distributed device **108a** from among a group of simulated distributed devices **108a** in the simulated environment **106**.

In block **208**, the computing device **102** modifies at least one device simulation property for the simulated distributed device **108a**. The computing device **102** may or may not modify the at least one device simulation property based on the event characteristics at the current time step and the spatial location of the simulated distributed device **108a** at the current time step. For example, the computing device **102** can modify device rules **114a** (e.g., a mathematical distribution or a mathematical function thereof) defining the device simulation property. The computing device **102** may modify the device rules **114a** based on the event characteristics at the current time step and the spatial location of the simulated distributed device **108a** at the current time step. In this way, one or more device simulation properties can be

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modified over time, e.g., as the event characteristics change and/or the spatial location of the simulated distributed device **108a** changes.

In block **210**, the computing device **102** determines if there is another simulated distributed device **108b** that needs to have its device rules **112a-c** modified for the current time step. If so, the process returns to block **206** and repeats. Once all of the simulated distributed devices **108a-c** have had their device rules **112a-c** modified for the current time step, the process can proceed to block **212**.

In block **212**, the computing device **102** can run the simulation (e.g., by executing the simulation software **104**) for the current time step. This can produce simulation outputs for the current time step that are at least partially impacted by the spatiotemporal event **116**.

In block **214**, the computing device **102** provides the simulation output(s) for the current time step as input to a target software application **110**, for example, to determine how the target software application **110** responds to the simulation outputs. The computing device **102** may also log the results of this step, which may later be reviewed by a developer of the target software application **110**. The process may then return to block **204** and iterate as needed. In this way, the target software application **110** can be tested under a variety of simulated conditions, and more particularly under dynamically changing conditions in response to a simulated spatiotemporal event **116**.

FIG. 3 depicts a block diagram of another example of a system **300** for testing responses of software applications to spatiotemporal events using simulated environments according to some aspects. The components shown in FIG. 3 are exemplary, and other examples can include more components, fewer components, different components, or a different configuration of the components shown in FIG. 3.

The system **300** includes a processing device **302** communicatively coupled with a memory device **304**. In some examples, the processing device **302** and the memory device **304** can be part of a computing device, such as computing devices **102**. The processing device **302** can include one processing device or multiple processing devices. Non-limiting examples of the processing device **302** include a Field-Programmable Gate Array (FPGA), an application-specific integrated circuit (ASIC), a microprocessor, etc. The processing device **302** can execute instructions **306** stored in the memory device **304** to perform operations. In some examples, the instructions **306** can include processor-specific instructions generated by a compiler or an interpreter from code written in any suitable computer-programming language, such as C, C++, C#, etc.

The memory device **304** can include one memory device or multiple memory devices. The memory device **304** can be non-volatile and may include any type of memory device that retains stored information when powered off. Non-limiting examples of the memory device **304** include electrically erasable and programmable read-only memory (EEPROM), flash memory, or any other type of non-volatile memory. In some examples, at least some of the memory device can include a medium from which the processing device **302** can read instructions **306**. A computer-readable medium can include electronic, optical, magnetic, or other storage devices capable of providing the processing device **302** with computer-readable instructions **306** or other program code. Non-limiting examples of a computer-readable medium include magnetic disk(s), memory chip(s), ROM, random-access memory (RAM), an ASIC, a configured



processing device, optical storage, or any other medium from which a computer processing device can read the instructions **306**.

In some examples, the processing device **302** can execute simulation software **104** to generate a simulated environment **106** having simulated distributed devices **308a-c** positioned at various spatial locations in the simulated environment **106**. The simulated distributed devices **308a-c** are configured to emulate operation of physical distributed devices corresponding to the simulated distributed devices **308a-c**. The processing device **302** can then simulate a spatiotemporal event **116** propagating through the simulated environment **106** by modifying a device simulation property **310a-c** of each simulated distributed device **108a-c** based on the spatiotemporal event **116** and a respective spatial location of the simulated distributed device **108a-c** in the simulated environment **106**. This can produce simulation outputs **308** impacted by the spatiotemporal event **116**. The processing device **302** can then test how a target software application **110** responds the spatiotemporal event **116** by providing the simulation outputs **308** as input to the target software application **110**. The target software application **110** is separate from the simulated environment **106**.

FIG. 4 depicts a flow chart of another example of a process for testing responses of software applications to spatiotemporal events using simulated environments according to some aspects. Other examples can include more steps, fewer steps, different steps, or a different order of the steps than is shown in FIG. 4. The steps of FIG. 4 are discussed below with reference to the components discussed above in relation to FIG. 3.

In block **402**, a processing device **302** executes simulation software **104** to generate a simulated environment **106** having simulated distributed devices **308a-c** positioned at a plurality of spatial locations in the simulated environment **106**. The simulated distributed devices **308a-c** are configured to emulate operation of physical distributed devices corresponding to the simulated distributed devices **308a-c**.

In block **404**, the processing device **302** simulates a spatiotemporal event **116** propagating through the simulated environment **106** by modifying a device simulation property **310a-c** of each simulated distributed device **108a-c** based on the spatiotemporal event **116** and a respective spatial location of the simulated distributed device **108a-c** in the simulated environment **106**. This can produce simulation outputs **308** impacted by the spatiotemporal event **116**.

In block **406**, the processing device **302** provides the simulation outputs **308** as input to a target software application **110** that is separate from the simulated environment **106** to test a response to the spatiotemporal event **116** by the target software application **110**.

The foregoing description of certain examples, including illustrated examples, has been presented only for the purpose of illustration and description and is not intended to be exhaustive or to limit the disclosure to the precise forms disclosed. Numerous modifications, adaptations, and uses thereof will be apparent to those skilled in the art without departing from the scope of the disclosure. For instance, any example(s) described herein can be combined with any other example(s) to yield further examples.

The invention claimed is:

**1.** A system comprising:

a processing device; and

a memory device including instructions that are executable by the processing device for causing the processing device to:

execute simulation software to generate a simulated environment having a simulated distributed device configured to emulate operation of a physical distributed device;

simulate a spatiotemporal event propagating through the simulated environment to produce a simulation output impacted by the spatiotemporal event; and

provide the simulation output as input to a target software application that is separate from the simulated environment to test a response of the target software application to the spatiotemporal event.

**2.** The system of claim **1**, wherein the memory device further includes instructions that are executable by the processing device for causing the processing device to simulate the spatiotemporal event as spatially propagating through the simulated environment by modifying a device simulation property of the simulated distributed device.

**3.** The system of claim **2**, wherein the device simulation property is defined by a mathematical distribution, and modifying the device simulation property comprises modifying the mathematical distribution.

**4.** The system of claim **2**, wherein the device simulation property is defined by a mathematical function, and modifying the device simulation property comprises modifying the mathematical function.

**5.** The system of claim **2**, wherein the device simulation property is modified based on the spatiotemporal event and a spatial location of the simulated distributed device in the simulated environment.

**6.** The system of claim **2**, wherein the memory device further includes instructions that are executable by the processing device for causing the processing device to simulate the spatiotemporal event as spatially propagating through the simulated environment over a series of time steps by modifying the device simulation property of the simulated distributed device at each time step in the series.

**7.** The system of claim **6**, wherein the device simulation property is modified at each time step based on (i) an event characteristic at the time step, and (ii) a spatial location of the simulated distributed device in the simulated environment at the time step.

**8.** The system of claim **7**, wherein the device simulation property is modified at each time step based on a distance between (i) the spatiotemporal event in the simulated environment, and (ii) the spatial location of the simulated distributed device in the simulated environment.

**9.** The system of claim **1**, wherein the simulated distributed device is a simulated Internet-of-Thing (IOT) device, the physical distributed device is a physical IOT device, and the target software application is an IOT application configured to receive an input from the physical IOT device.

**10.** The system of claim **1**, wherein the memory device further comprises instructions that are executable by the processing device for causing the processing device to:

receive a user customization as to how to simulate the spatiotemporal event in the simulated environment; and simulate the spatiotemporal event in the simulated environment in accordance with the user customization.

**11.** A method comprising:

executing, by a processing device, simulation software to generate a simulated environment having a simulated distributed device configured to emulate operation of a physical distributed device;

simulating, by the processing device, a spatiotemporal event propagating through the simulated environment to produce a simulation output impacted by the spatiotemporal event; and



providing, by the processing device, the simulation output as input to a target software application that is separate from the simulated environment to test a response of the target software application to the spatiotemporal event.

**12.** The method of claim **11**, further comprising simulating the spatiotemporal event as spatially propagating through the simulated environment by modifying a device simulation property of the simulated distributed device.

**13.** The method of claim **12**, wherein the device simulation property is defined by a mathematical distribution or a mathematical function, and wherein modifying the device simulation property comprises modifying the mathematical distribution or the mathematical function.

**14.** The method of claim **12**, wherein the device simulation property is modified based on the spatiotemporal event and a spatial location of the simulated distributed device in the simulated environment.

**15.** The method of claim **12**, further comprising simulating the spatiotemporal event as spatially propagating through the simulated environment over a series of time steps by modifying the device simulation property of the simulated distributed device at each time step in the series.

**16.** The method of claim **15**, wherein the device simulation property is modified at each time step based on (i) an event characteristic at the time step, and (ii) a spatial location of the simulated distributed device in the simulated environment at the time step.

**17.** The method of claim **16**, wherein the device simulation property is modified at each time step based on a distance between (i) the spatiotemporal event in the simu-

lated environment, and (ii) the spatial location of the simulated distributed device in the simulated environment.

**18.** The method of claim **11**, wherein the simulated distributed device is a simulated Internet-of-Thing (IOT) device, the physical distributed device is a physical IOT device, and the target software application is an IOT application configured to receive an input from the physical IOT device.

**19.** The method of claim **12**, further comprising:

receiving, by the processing device, a user customization as to how to simulate the spatiotemporal event in the simulated environment; and

simulating, by the processing device, the spatiotemporal event in the simulated environment in accordance with the user customization.

**20.** A non-transitory computer-readable medium comprising program code that is executable by a processing device for causing the processing device to:

execute simulation software to generate a simulated environment having a simulated distributed device configured to emulate operation of a physical distributed device;

simulate a spatiotemporal event propagating through the simulated environment to produce a simulation output impacted by the spatiotemporal event; and

provide the simulation output as input to a target software application that is separate from the simulated environment to test a response of the target software application to the spatiotemporal event.

\* \* \* \* \*